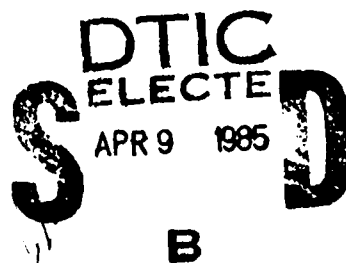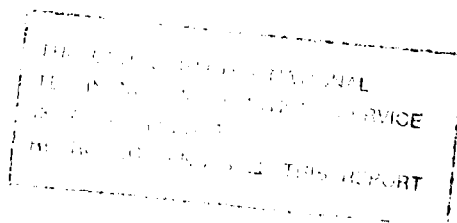AD-A152 257

# DEPARTMENT OF DEFENCE

## DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

## MATERIALS RESEARCH LABORATORIES

### MELBOURNE, VICTORIA

## REPORT

## MRL-R-937

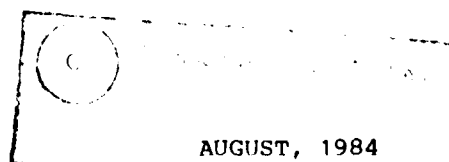SURFACE COATINGS FOR LOW EMITTANCE IN THE
THERMAL SURVEILLANCE BAND

R.L. Calvert, J.A. Gagliardi and
A.D. McLachlan

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## SURFACE COATINGS FOR LOW EMITTANCE IN THE THERMAL SURVEILLANCE BAND

R.L. Calvert, J.A. Gagliardi and
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## ABSTRACT

Paint or semiconductor films may both be used to provide low emittance coatings for countersurveillance in the 8-14 μm wavelength range. Although the emittances of paint coatings are usually larger than those of semiconductor films, they are simpler to produce, more robust and are inexpensive. In the present work, a variety of paint samples were studied to determine their emittance, total hemispherical reflectance and angular reflectance distribution at 10.6 μm. The best results were achieved when various concentrations of 70 μm aluminium flake were incorporated into an inorganic phosphate binder, yielding emittances in the range 0.20 - 0.60 with diffuse reflectance distributions. The application of dust or water to these coatings resulted in large increases in emittance.

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Paint or semiconductor films may both be used to provide low emittance coatings for countersurveillance in the 8-14 μm wavelength range. Although the emittances of paint coatings are usually larger than those of semiconductor films, they are simpler to produce, more robust and are inexpensive. In the present work, a variety of paint samples were studied to determine their emittance, total hemispherical reflectance and angular reflectance distribution at 10.6 μm. The best results were achieved when various concentrations of 70 μm aluminium flake were incorporated into an inorganic phosphate binder, yielding emittances in the range 0.20 - 0.60 with diffuse reflectance distributions. The application of dust or water to these coatings resulted in large increases in emittance.

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# SURFACE COATINGS FOR LOW EMITTANCE IN THE

# THERMAL SURVEILLANCE BAND

## 1. INTRODUCTION

### 1.1 Coatings for Low-Emittance

Thermal imaging is now widely used for day and night surveillance of military equipment and personnel. The technique is based on the detection of thermal "self emission" radiation in the 8-14 μm wavelength band and is capable of detecting temperature differences between an object and its surroundings of less than 1.0°C [1]. Not unexpectedly, considerable effort is now directed at the investigation of possible countersurveillance methods and these include conventional near-infrared camouflage nets used with thermal infrared baffles as well as covering the surface of the object with a low emittance coating to minimise thermal emissions [2]. Information regarding coatings which may be suitable for this latter purpose is readily available since there are a number of applications in industry where durable, low emittance coatings are utilised, for example:

(1)     transparent coatings for energy efficient window and automobile glass [3];

(2)     transparent but conducting coatings on glass [4] and

(3)     the solar energy industry, where surface coatings are required for solar collectors which maximise the absorption of solar energy at wavelengths up to 2 μm, yet minimise the thermal re-emission at longer wavelengths [5].

The coatings used and being investigated for the above applications are of two types, namely optical quality semiconductor thin films and paint. The semiconductor thin films usually provide much lower emittances (typically <0.05) than can be obtained from paint (~0.15) and many combinations of different materials have been studied in inhomogeneous [6] or graded-index metal/dielectric interference films [7], as well as single layers of diamond-

1

like carbon coatings [8] or doped semiconductors [9]. These films have been deposited on metal, glass and pl stic substrates. Although semiconductor films do provide coatings with the lowest emittances, their manufacture and application requires specialised vacuum and thickness monitoring equipment and as a consequence, the films are expensive to produce. In addition, the performance of these films deteriorates when they are exposed to normal weathering conditions and several research laboratories are actively investigating coating soiling mechanisms, such as cementation and organic deposition, which lead to an increase in coating emittance [10].

Research into low emittance paint is mainly carried out in the solar energy industry [11, 12] and can be divided into two categories, thickness-sensitive (<1 µm thick) and thickness-insensitive (>1 µm) paints. The former are produced by the deposition of an optically thin layer of an IR transmitting paint on to a highly thermally reflecting (i.e. low emittance) substrate. Investigations of suitable particulates have included semiconductors, metal oxides and black pigment. Binders considered included olefin based polymers, acrylics, urethanes, etc. Emittance values as low as 0.15 have been obtained but, as with semiconductor films, the controlled deposition of a thin film of paint is relatively difficult and expensive.

In contrast, the thickness insensitive paints are much simpler to manufacture and apply and can be sprayed or deposited on to any type of substrate regardless of emittance. Either a low emittance base coat is applied to a substrate or a low emittance metal flake must be included in the paint. It is the latter approach which was used in this work. Values of emittance comparable to those for thickness-sensitive paints have been obtained [11].

## 1.2   Other Considerations

A low-emittance paint coating applied to an opaque substrate must, by consideration of the laws of radiation, have a high reflectance. Of concern to a countersurveillance application, but not of interest to the solar and related industries, is the angular distribution of the reflected radiation. This arises because the radiation entering a thermal imager from a target under surveillance has two components. In addition to the self-emission or thermal component specified by the target black body temperature and emissivity, there is a component arising from target reflectance. Consequently, a surface coating applied to a target must be capable of minimising the sum of the above components as seen by an observer at an unknown location. This requires the reflected component to appear equally bright from all directions, which implies a Lambertian distribution of reflected energy.

Any attempt to modify the thermal signature of a target requires a knowledge of not only the emittance and reflectance characteristics associated with natural and man-made materials and objects but must also include such considerations as:

(1)   the extent of 8-14 µm radiation emanating from the sky during the day and at night [13];

2

(2) ·the geometry, surface topography, and surface cleanliness of the target and the aspect likely to be presented to an observer [14] and

(3) the suppression of local regions of high temperature or temperature contrast on a target, e.g. ships' funnels [15], vehicle exhaust emissions [8], tank gun barrels [8] and the heating of surfaces by the sun [1].

## 1.3 Previous Reflectance Measurements

The source of radiation which is most convenient for the investigation of reflectance (and emittance) in the 8-14 µm band is a $CO_2$ laser operating at 10.6 µm. Although most paint binders may have a complex distribution of absorption bands within the 8-14 µm wavelength range, the optical characteristics of paint pigments are generally absorbing to wavelengths in this range.

Detailed information regarding reflectance and reflectance distributions at this wavelength for a variety of materials is available as a consequence of research into the effective operation of laser radar [16,17] and laser range finders [14]. For example, Henshall and co-workers [16] have measured the reflectance distribution from over 50 wet and dry natural and man-made materials using a $CO_2$ Laser. Measurements made by O'Conner [18], although at 1.06 µm, warn that reflectance values depend very strongly on surface cleanliness.

A description of terms and definitions used in reflectometry is provided by Judd [19] and Overington [20]. Measurement standards suitable for use at 10.6 µm are provided by Stuhlinger [21] who also investigates the effects of varying particle size on the resulting reflectance distribution.

## 1.4 Previous Emittance Measurements

Several laboratories have investigated low emittance coatings suitable for thermal countersurveillance [2,8,15,22]. A detailed evaluation of a low emittance naval paint (haze grey) was undertaken by Henshall [15], but the composition of the paint was not revealed. An emittance of 0.46 was obtained and measurements of retroreflectance versus viewing angle indicated that the reflectance distribution was diffuse. In comparison, a very specular return was obtained from a conventional naval paint 1GP61D, which had an emittance of ~0.96. It was pointed out that the haze grey low-emittance paint produced strong reflections from nearby heat sources, such as the ship's funnel and sunlight, and that when used alone it would not provide a large reduction in contrast between heated areas and their surroundings. Similar comments have been made by Troughton [8] regarding thermal camouflage based on a (carbon) diamond-like hard coating, 1 µm thick with an emittance of approximately 0.15. Sheets of this material were found to be very effective in reducing emissions from an exhaust, but sky reflections were very strong. A stepped-profile sheet was then used which mostly reflected radiation from the ground, but the target under surveillance was still found to be 15-30°C hotter than the background. No information regarding reflectance

3

distributions from the coatings was provided, nor on the effect of surface contamination.

To investigate further the feasibility of using low emittance thickness-insensitive paints for thermal countersurveillance, the experiments described in this report were undertaken to evaluate the emittances and reflectance distributions obtained from a variety of pigments and binders. The effect of surface contamination has been qualitatively investigated, and the possibility of using disruptive patterning to break up thermal signatures has been addressed.

## 2.    EXPERIMENTAL DETAILS

### 2.1    Paint Coatings

Paint coatings suitable for this investigation were initially selected by an inspection of paint binder and pigment infrared absorptance and transmittance data presented in the Infrared Spectroscopy Atlas [22]. In addition, several readily available paints were examined (e.g. a "Dulux" acrylic latex paint) as were paint coatings of particular interest (e.g. as on an F-111 aircraft panel). Most binders and pigments presented in the Atlas exhibited substantial absorption bands in the 8-14 μm range and were not suitable for providing low emittance coatings. Nevertheless, some possible low emittance coatings were identified for study and these, as well as the other coatings examined are summarised in Table 1. It should be emphasised that the list in Table 1 is by no means exhaustive of available materials but the coatings examined are representative of the variety of results that can be obtained. All coatings studied were also required to have characteristics desirable for countersurveillance in the visible range of wavelengths, e.g. dull, low sheen finish, dark pigment.

Most paint coatings were produced using conventional procedures and were brushed uni-directionally on to sandblasted aluminium panels 150 x 75 x .5 mm in size. No special precautions were taken to control coating thickness or texture but measurements made using an Elcometer eddy current thickness monitor indicated that binder coating thickness was usually in the 10-50 μm range. Many samples were pigmented by the addition of titanium dioxide, zinc oxide, or aluminium (powder or flake). Various concentrations of pigment were added to some binders (see Table 1) and, in particular, the influence of aluminium flake particle size on emittance was investigated for average particle sizes of 12 and 70 μm. The concentration of pigment in each sample is specified by weight.

A paint incorporating aluminium dust in an inorganic phosphate binder (IPB) was studied quite extensively. This was made by dispersing an aluminium powder in a magnesium and chromium phosphate solution. Hexavalent chromium was included to inhibit chemical attack of the aluminium particles. This solution was brushed on to sandblasted aluminium substrate and cured by gradually heating to 350°C. Further details of this binder are given in Table 5.

4

## 2.2 The Influence of Dust and Water on Coating Characteristics

The effect of dust and water on the emittance and reflectance distribution from: (i) sandblasted aluminium; (ii) an IPB plus aluminium powder coating, and (iii) an IPB plus aluminium flake coating was examined qualitatively. The dust samples, obtained from Templestowe, Victoria, were first ground to a fine powder in a mortar and pestle and applied to the surface in one of two ways. Either a "light" layer of dust was applied using a dust covered brush, or dust and water were mixed to form a slurry and a "heavy" layer applied liberally by brush and allowed to dry. The "light" layer of dust modified the appearance of the coatings only slightly but "heavy" coatings resulted in a quite marked visual change. The effect of water on the optical characteristics of sandblasted aluminium was studied by wiping the surface with a dampened tissue.

## 2.3 Reflectance Measurements

A schematic of the apparatus used to study sample reflectance distributions is shown in Fig. 1. The samples were located above the axis of rotation of a 600 mm diameter goniometer table and were irradiated by 10.6 µm radiation from a 3-W $CO_2$ laser. The laser radiation was modulated at 16 Hz by a rotating chopper blade and the radiation scattered from the sample was synchronously detected by a moveable thin film thermopile detector (Sensors, Inc) connected to an Ortec-Brookdeal (model 9501) lock-in-amplifier (LIA). The output from the LIA, proportional to reflectance, was connected to the Y axis of a Hewlett Packard (HP) 7041A X-Y recorder. The thermopile detector incorporated an 8-14 µm bandpass filter and had an active area consisting of a metal oxide black. It was mounted on the goniometer table 95 mm from the axis of rotation and subtended a solid angle of $2.5 \times 10^{-4}$ sr with respect to the sample position.

The $CO_2$ laser was fixed in position throughout the experiment and the output was monitored by means of a germanium beam splitter and a Scientech Inc laser power meter calibrated to provide absolute power measurements to within 3%. A variable aperture directly in front of the laser limited the beam diameter incident on the targets to either 3 or 5 mm.

The painted panels were clamped in place on the sample holder and could be independently rotated relative to the table to enable the angle of incidence ($\theta$) to be varied in the range 0° - 80° (10° calibrations). In addition, the detector could be rotated in an arc in front of the target and the position of the table, and hence detector, was specified by the viewing angle ($\delta$) read from a micrometer. A 10-turn potentiometer attached to the side of the table provided an analogue signal proportional to $\delta$ and this was connected to the X axis of the HP 7041A recorder. A reflectance versus $\delta$ plot for a given angle of incidence was thus obtained by a slow manual rotation of the table. A further adjustment on the sample holder ensured that each sample could be adjusted so that the azimuthal angle ($\beta$) was zero. This adjustment was especially important to optimise the detected signal from highly specular targets and ensured that all measurements refer to scattering in the plane of incidence.

The reflectance distribution from each sample in the plane of incidence was compared with that of sandblasted aluminium and no attempt was made to quantify the specular or diffuse contributions within each plot.


## 2.4  Absorptance Determination

The calorimetric technique described by Gibbs and Butterfield [23] was used to determine the absorptance (equivalent to emittance [1]) of the samples. This entailed measuring the temperature rise when the $CO_2$ laser beam irradiated the samples for a short time. To ensure that temperature rises could be readily measured, the samples used were 25 x 25 x .5 mm and were suspended by fine cotton threads within a rectangular holder which could be translated laterally in front of the laser beam. This allowed different locations on each sample to be irradiated.

The temperature of the sample was measured using a copper-constantan thermocouple attached to the centre of the sample rear surface. The temperature of the sample and the laser power output were recorded and, in additi⌐⌐, voltages proportional to these quantities were connected to an HP 3421A data acquisition and control unit. This latter apparatus was interfaced to an HP 41CV calculator and was used for automated data acquisition as well as for synchronising the operation of an electronic shutter, thereby controlling sample laser irradation.

If $\dot{\theta}_1$, $\dot{\theta}_2$ and $\dot{\theta}_3$ are the rates of change of temperature and $\theta_1$, $\theta_2$ and $\theta_3$ are the mean temperatures before, during and after laser irradiation, then it can be shown using Newton's Law of Cooling that the power $(P_A)$ absorbed by the sample is given by

$$P_A = C \left( \dot{\theta}_2 - \dot{\theta}_1 - (\dot{\theta}_3 - \dot{\theta}_1) \frac{(\theta_2 - \theta_1)}{(\theta_3 - \theta_1)} \right) \qquad (1)$$

where C, the thermal capacity of the sample, is readily determined from the product of sample mass and specific heat.

During each measurement, sufficiently long irradiation and cooling times were allowed for $\dot{\theta}_2$ to become constant and for $\dot{\theta}_3$ to become well defined. A typical recorder trace is shown in Fig. 2.[3] Under calculator control, values for $\theta_i$ (i = 1,2,3) and $\dot{\theta}_i$ were determined during the sample irradiation cycle and equation 1 was solved to obtain a value for $P_A$. This complete procedure was then repeated 5 times for each sample. Prior to each laser heating cycle a measurement of laser power was obtained and stored in the calculator.

At regular intervals during each experiment, measurements were also made using a 25 mm diameter aluminium anodised disc whose absorptance was precisely known (98%). This measurement provided the basis for specifying the power incident on the other samples being investigated and hence their

bsolute absorptance α, and thus emittance, could be obtained. The total
emispherical reflectance, $w_{2\pi}$ , is then 1-α.


## 3. RESULTS


### .1 Aluminium


     Absorptance and reflectance measurements were first obtained from
ﾋolished and sandblasted aluminium to examine apparatus reliability and
ﾑeasurement reproducibility. The results obtained from these two samples are
ﾑummarised in Table 2 and are ın close agreement with literature values. The
ﾋredominant error involved in absorptance estimates is due to variations
rising from irradiation of different regions of the sample. This error was
ﾋypically 4% and applied to most samples studied.


     The reflectance distribution for the two aluminium samples is shown
ın Fig. 3. As expected, the polished aluminium produced a very specular
ﾋcattering profile with a negligible diffuse component. Sandblasted aluminium
ﾑowever, has a very diffuse reflectance distribution with a small specular
ﾋomponent superimposed. A semi-empirical analysis of this latter curve by
ﾋrighton and Gaylor [24] indicated that approximately 75% of the total
ﾑemispherical reflectance was scattered diffusely. The angular distribution
ıs not Lamhᵧrtian but is expected to be quite satisfactory for
ﾋountersurveillance requirements. The reflectance distribution from
ﾋandblasted aluminium for several angles of incidence is shown in Fig. 4,
ﾋonfirming that a diffuse reflectance distribution is maintained
ıs θ increases [18].


### ⅃.2 Paint Coatings


     A summary of absorptance (emittance) and total hemispherical
ﾍeflectance data for the coatings investigated is provided in Table 3.
ﾋepresentative reflectance distribution plots from some samples are provided
ın Figs. 5-7 and include the distribution from sandblasted aluminium for
ﾋomparison. In all cases the angle of incidence was fixed at 10°. Many of
ﾋhe samples exaﾑined would be unsuitable low emittance coatings since they had
ı high absorptaﾍ ɔe (> 78%) coupled with a specular reflectanɔe distribution.
ﾍhis was the caﾋ e for all paint binders tested (e.g. alkyd, chlorinated
ﾍubber, epoxy, latex and rosin). A marked reduction in emittance was usually
ﾋbtained by the addition of an aluminium pigment. These results are now
ﾍiscussed.


### ⅃lkyd and Aluminium Powder


     Quite high concentrations of Al powder were needed to influence the
ﾋmittance from an alkyd/Al powder combination. The aluminium probably settled
ﾋo the bottom of the coating during preparation and the emittance at low

concentrations was thus determined by the alkyd. In all alkyd/Al powder samples the reflectance distribution was specular.


## Alkyd and Aluminium Flake

Aluminium flake added to alkyd was much more effective than powder in producing a low emittance coating (Table 3) with optimum values of 0.16 and 0.25 for flake sizes of 70 and 12 μm respectively. The reflectance distributions obtained from several 70 μm concentrations are plotted in Fig. 5. It is apparent that the large specular peak from the alkyd can be suppressed and broadened and it was observed that 70 μm flake resulted in a much broader distribution than could be obtained from 12 μm flake.


## Inorganic Phosphate Binder and Aluminium Powder

A number of paint compositions, based on a type of aluminium coating were investigated. The coatings comprised an inorganic phosphate binder (IPB) and various concentrations of aluminium powder. A paint with 40% by weight of aluminium powder was found to give an emittance of 0.60 with an almost Lambertian reflectance distribution (see Fig. 6).

Effort was directed at reducing the emittance and yet maintaining the diffuse reflectance by varying the aluminium content. It was found that the aluminium powder content could be increased to approximately 50% so that the emittance decreased to 0.46 and still maintain a diffuse reflectance. Further addition of aluminium powder did not produce a usable paint and no improvement on the value of 0.46 was possible.


## Inorganic Phosphate Binder and Aluminium Flake

As shown in Table 3, considerable reduction in emittance was achieved if aluminium flake was added to the inorganic phosphate binder. Most of the coatings investigated incorporated 70 μm Al flake and the lowest values of emittance obtained were in the 0.18 - 0.25 range. As the aluminium flake concentration increased, the reduction in absorptance was accompanied by an increased specular contribution to the reflectance distribution (see Fig. 6). All samples had a specular component exceeding that which occurred in sandblasted aluminium (25%). These particular coatings exhibited considerably more texture and surface topographical variations compared with other samples investigated and measurements showed that brushing techniques could result in differences (~10%) in emittance and reflectance data from coatings which had nominally the same composition.


## 3.3   Changes Produced by Dust and Water

The application of dust and water had a dramatic effect on the emittance and reflectance of the samples studied. The results of the emittance measurements are summarised in Table 4 whilst typical reflectance
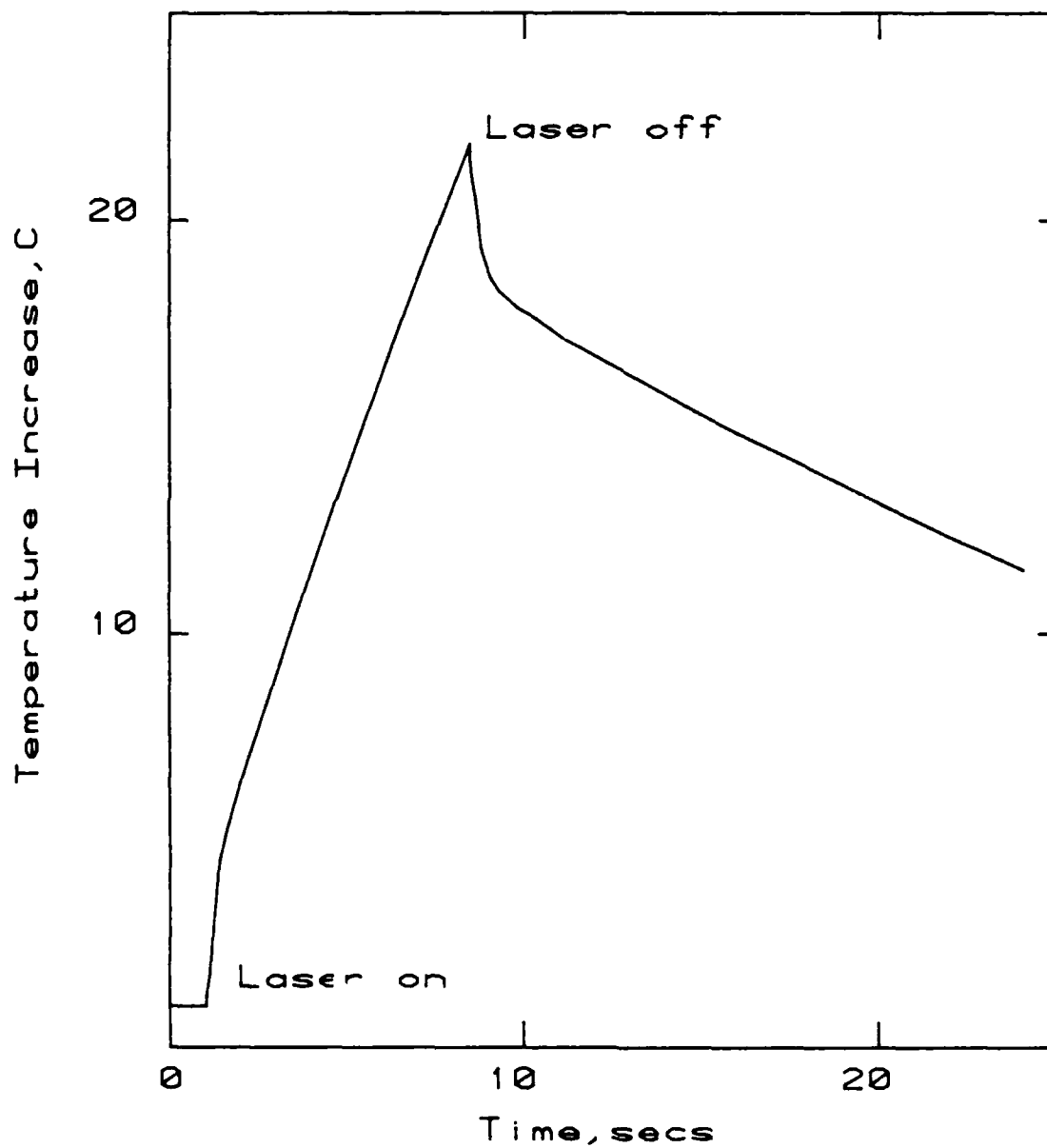
FIG. 2 - A typical temperature versus time profile during an absorptance measurement.
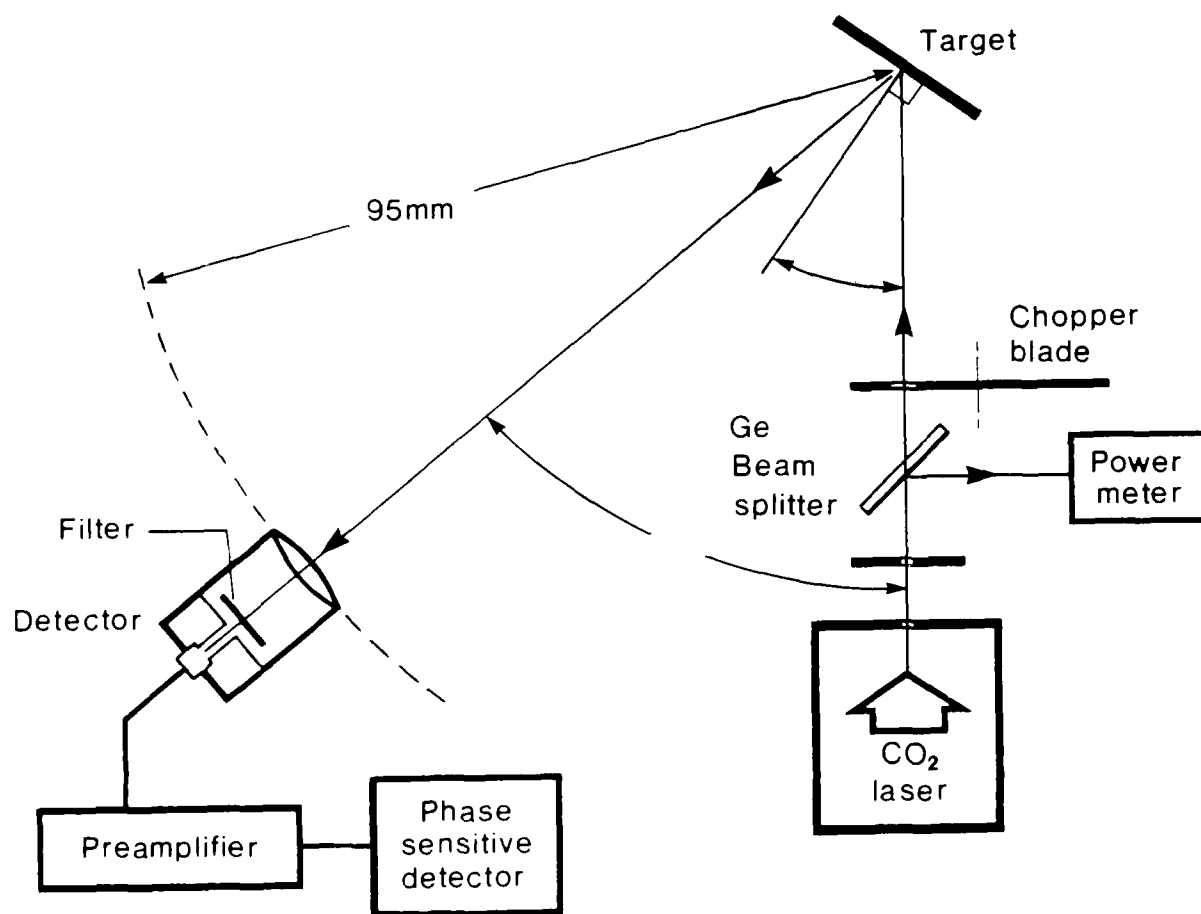
FIG. 1 - A schematic of the apparatus used to study reflectance.

## TABLE 6

## COMPOSITION OF ZINC RICH EPOXY PAINT (2-PACK)

|  | Coating |
|---|---|
| **Base** | |
| Zinc dust | 81.5 |
| Epoxy resin (epikote 1001) | 34.2 |
| Bentone 27 | 8.7 |
| Solvent | 105.5 |
| **Curing Solution** | |
| Versamid 115 | 18.3 |
| Solvent | 18.3 |

**Suppliers**

Epoxy Resin - Shell Chemicals

Versamid 115 - A.C. Hatrick Chemicals

TABLE 5

COMPOSITION OF IPB

Inorganic Phosphate Binder

| | |
|---|---|
| Magnesium oxide | 26 gm |
| Phosphoric acid | 145 |
| Chromic acid | 28 |
| Ethanol | 10 |
| Water | 391 |
| | ——— |
| | 600 |

## TABLE 4

### INFLUENCE OF DUST AND WATER ON ABSORPTANCE ($\alpha$)

### AND TOTAL HEMISPHERICAL REFLECTANCE ($\rho_{2\pi}$)

| COATING | $\alpha$ | $\rho_{2\pi}$ | | COMMENTS |
|---|---|---|---|---|
| sandblasted Al | 0.24 | 0.76 | | diffuse |
| + light layer dust | 0.44 | 0.56 | | diffuse |
| + heavy layer dust | 0.84 | 0.16 | | diffuse |
| + cleaned ($H_2O$) and dried | 0.34 | 0.66 | | diffuse |
| + $H_2O$ | 0.60 | 0.40 | | diffuse |
| then dried | 0.32 | 0.68 | | diffuse |
| | | | | |
| Inorganic Phosphate + 40% aluminium powder | 0.60 | 0.40 | | diffuse (Lambertian) |
| + heavy layer of dust | 0.89 | 0.11 | | diffuse |
| | | | | |
| Inorganic Phosphate + 20% by weight of 70 μm Al flake | 0.38 | 0.62 | | diffuse with specular component |
| + light layer dust | 0.52 | 0.48 | ) | diffuse with a much |
| cleaned, then dried | 0.48 | 0.52 | ) | decreased specular |
| + heavy layer dust | 0.88 | 0.12 | ) | component |

TABLE 3

(Continued)

| | Coating | $\alpha$ | $\rho_{2\pi}$ | Comments |
|---|---|---|---|---|
| 14. | Inorganic phosphate plus aluminium powder | | | |
| | a.  30% by wt | 0.78 | 0.22 | diffuse |
| | b.  50% by wt | 0.46 | 0.54 | diffuse |
| 15. | Inorganic phosphate plus aluminium flake | | | |
| | a.  12 µm  20% by wt | 0.40 | 0.60 ) | diffuse with |
| | b.  70 µm  20% by wt | 0.42 | 0.57 ) | specular component |
| | c.  70 µm  30% by wt | 0.25 | 0.44 ) | diffuse, specular |
| | d.  70 µm  38% by wt | 0.18 | 0.82 ) | component increasing |
| 16. | Inorganic phosphate plus aluminium powder + aluminium flake | 0.42 | 0.58 | diffuse |

C.  Additional Samples

| | | | | |
|---|---|---|---|---|
| 17. | Aircraft panel from F111 | 0.90 | 0.10 | specular, small diffuse component. |

## TABLE 3

### COATING ABSORPTANCE ($\alpha$) AND TOTAL HEMISPHERICAL REFLECTANCE ($\rho_{2\pi}$)

| Coating | $\alpha$ | $\rho_{2\pi}$ | Comments |
|---|---|---|---|
| **A. Clear Coatings** | | | |
| 1. Chlorinated rubber lacquer | 0.84 | 0.16 | Specular |
| 2. Epoxy lacquer | 0.89 | 0.11 | Specular |
| 3. Acrylic latex | >0.95 | | Specular |
| 4. Alkyd varnish | 0.89 | 0.11 | Specular |
| **B. Pigmented Coatings** | | | |
| 5. Zinc rich epoxy | 0.73 | 0.27 | Specular, diffuse component |
| 6. Rosin + aluminium powder | not measured | | Specular |
| 7. Zince dust + inorganic silicate | 0.82 | 0.18 | Specular, diffuse component |
| 8. No. 7 plus aluminium powder | 0.53 | 0.47 | Specular, diffuse component |
| 9. Interior house paint | 0.78 | 0.22 | diffuse (Lambertian) |
| 10. Alkyd enamel | 0.89 | 0.12 | Specular |
| 11. Alkyd plus aluminium powder | | | |
|    a. 5% by wt | 0.90 | 0.10 | Specular |
|    b. 33% by wt | 0.93 | 0.07 | Specular |
|    c. 50% by wt | 0.78 | 0.22 | Specular |
| 12. Alkyd plus aluminium flake | | | |
|    a. 70 µm   5% by wt | 0.61 | 0.39 | Specularity decreases |
|    b. 70 µm   33% by wt | 0.19 | 0.81 | as concentration of Al |
|    c. 70 µm   50% by wt | 0.16 | 0.85 | particles increases |
|    d. 12 µm   5% by wt | 0.68 | 0.31 | 70 µm flake more |
|    e. 12 µm   33% by wt | 0.25 | 0.75 | effective |
| 13. Inorganic phosphate plus 40% aluminium powder | 0.60 | 0.40 | diffuse (Lambertian) |
|    a. Inorganic phosphate | no measurement possible | | |

TABLE 2

ABSORPTANCE ($\alpha$) AND TOTAL HEMISPHERICAL REFLECTANCE ($\rho_{2\pi}$)

FROM POLISHED AND SANDBLASTED ALUMINIUM

|                       | $\alpha$        | $\rho_{2\pi}$   |
|-----------------------|-----------------|-----------------|
| Polished Aluminium    | 0.02            | 0.98            |
| Sandblasted Aluminium | 0.24 ± 0.01     | 0.76 ± 0.03     |

TABLE 1
(continued)

| Coating | Resin/Trade Name | Supplier |
|---|---|---|
| 15. Inorganic phosphate plus aluminium flake[2] | | Refer No. 13 |
| 16. Inorganic phosphate plus aluminium powder[1] and flake[2] | | Refer No. 13 |
| **C. Post treated samples** | | |
| 17. Sample No. 13 + dust | | Dust obtained under house at Templestowe Vic |
| 18. Sample 16 + dust | | Refer No. 17 |
| **D. Additional Samples** | | |
| 19. Aircraft panel from F111 | | |
| 20. Sandblasted Aluminium | | Sandblasted with grit up to 250 µm |

1. Manufacturerd by Comalco. Grade 350 - dust.

2. Supplied by Hoecht Aust. Manufactured by Eckart-Werke W. Germany

    a. Standard aluminium powder lac oT average particle size 70 µm

    b. Standard aluminium powder fine lining AT. Average particle size 12 µm .

TABLE 1

SUMMARY OF COATINGS INVESTIGATED

|  | Coating | Resin/Trade Name | Supplier |
|---|---|---|---|
| **A.** | **Clear Coatings** | | |
| 1. | Chlorinated rubber lacquer | based on Alloprene R20 | I.C.I. Aust Ltd. |
| 2. | Epoxy lacquer | based Epikote 1001 | Shell Chemicals |
| 3. | Acrylic latex | based Kemrez 1216 | Kemrez Chemicals |
| 4. | Alkyd Varnish | based on Kemisol 3301 (67% Safflower alkyd) | Kemrez Chemicals |
| **B.** | **Pigmented Coatings** | | |
| 5. | Zinc rich epoxy | Epikote 1001 | MRL manufacture. Refer to Table 6 |
| 6. | Rosin + aluminium powder[1] | Wood rosin | |
| 7. | Zinc dust + inorganic silicate | Carboweld 11 | Vessey Chemicals |
| 8. | No. 7 plus aluminium powder[1] | | |
| 9. | Interior House paint | Acrylic latex | Dulux Wash & Wear Containing "Spindrift" vesicular polymer pigment |
| 10. | Alkyd enamel | Kemisol 3301 | MRL manufacture Pigmented with titanium dioxide and zinc oxide. |
| 11. | Alkyd plus aluminium powder[1] at various concentrations | Kemisol 3301 | Kemrez Chemicals |
| 12. | Alkyd + aluminium flake[2] at various concentrations | Kemisol 3301 | Kemrez Chemicals |
| 13. | Inorganic phosphate plus 40% aluminium powder[1] | | MRL manufacture. Refer table 5 |
| 14. | Inorganic phosphate plus aluminium powder[1] in varying concentration | | Refer No. 13 |

15.    Henshall, H. (1979). "An Infrared Evaluation of Two Naval Paints".
       Report DREV 4136/79. Defence Research Establishment, Valcartier,
       Quebec. Unclassified Report.

16.    Henshall, H., St. Pierre, P. and Courtenay, T.H. (1976). "Measurements
       of the Reflectance of Materials at 10.6 microns using a TEA-$CO_2$
       Ladar". Report DREV 4051/76, Defence Research Establishment,
       Valcartier, Quebec. Unclassified Report.

17.    Bichard, V.M., Davies, P.H., Hulme, K.F., Taylor, M.H. and Warner, J.
       "Diffuse and Specular Reflectivities of Sample Surfaces and Military
       Vehicles at $CO_2$ Laser Wavelengths". Memorandum RSRE 2899, Royal
       Signals and Radar Establishment, Malvern, U.K. Confidential Report.

18.    O'Connor, G.G. (1983). "Bistatic Reflectivity of Materials Used as
       Laser Targets". Report WSRL-0308-TM, Weapons Systems Research
       Laboratories, Adelaide, South Australia. Unclassified Report.

19.    Judd, D.B. (1967). "Terms, Definitions, and Symbols in
       Reflectometry". J. Opt. Soc. Am., 57, 445-452.

20.    Overington, I. (1976). "Vision and Acquisition". Pentech Press.
       London. 253-274.

21.    Stuhlinger, T. (1983). "Bidirectional Reflectance Distribution Function
       of Gold-plated Sandpaper". Opt. Eng., 22, SR-142 - SR-146.

22.    Federation of Societies for Coatings Technology. (1980). "An Infrared
       Spectroscopy Atlas for the Coatings Industry". Philadelphia,
       Pennsylvania, USA.

23.    Gibbs, W.E.K. and Butterfield, A.W. (1975). "Absorption of Thin Film
       Materials at 10.6 µm". Appl. Optics, 14, 3043-3046.

24.    Brighton, D.R. and Gaylor, K.J. (1984). "The Reflectance of a TBR
       Composite Material During Irradiation By a High-Power $CO_2$ Laser".
       Materials Research Laboratory Report. To be published.

# 5. REFERENCES

1.  Rosell, F.A. (1979). "Characterisation of the Thermal Scene". in The Fundamentals of Thermal Imaging Systems. Report AD/A-073-763. Naval Research Laboratory, Washington, D.C., U.S.A.

2.  Raisbeck, G., Aronson, J.R. and Key, M.E. (1981). "Design Goals for Future Camouflage Systems". Report AD-A099-223. Arthur D. Little Inc., USA. Unclassified Report.

3.  Haacke, G. (1982). "Materials for Transparent Heat Mirror Coatings". Proceedings of SPIE. 324, 10-15. Optical Coatings for Energy Efficiency and Solar Applications.

4.  Vossen, J.L. (1977). "Transparent Conducting Films". Physics of Thin Films, 2, 7-71.

5.  Lamport, C.M. (1982). "Durable Innovative Solar Optical Materials - the International Challenge". Proceedings of SPIE. 324, 1-7. Optical Coatings for Energy Efficiency and Solar Applications.

6.  Bastien, R.C., Austin, R.R. and Pottenger, T.P. (1978). "Inhomogeneous Metal/dielectric Selective Solar Absorbers". Proceedings of SPIE. 140, 140-157.

7.  Nyberg, G.A., Craighead, H.G. and Buhrman, R.A. (1982). "Roughened Graded-Index Cermet Photothermal Absorbers With very High Absorptivities". Proceedings of SPIE. 324, 117-120.

8.  Private communication between Dr G. Troughton, Royal Signals and Radar Establishment, Malvern, UK. and Dr P. Beckwith, Materials Research Laboratories, Australia.

9.  Frank, G., Kaver, E. and Köstlin, H. (1981). "Transparent Heat-Reflecting Coatings Based on Highly Doped Semiconductors". Thin Solid Films. 77, 107-117.

10. Proceedings of the Second Solar Reflective Materials Workshop (1980). Solar Energy Materials, 3, 1-346.

11. Moore, S.W. (1982). "Solar Absorber Selective Paint Research". Proceedings of SPIE. 324, 148-155.

12. Mar, H.B., Peterson, R.E. and Zimmer, P.B. (1976). "Low Cost Coatings for Flat-Plate Solar Collectors". Thin Solid Films. 39, 95-103.

13. Infrared Information and Analysis Centre. (1978). "The Infrared Handbook". (W.L. Wolfe and G.J. Zissis ed.). Office of Naval Research, Department of Navy, Washington D.C. Chapter 3.

14. Resumé of Target Reflectivity Measurements Made During RSRE $CO_2$ Laser Range-finding Experiments in Wet and Dry Conditions. Document RSRE BR-90769. Royal Signals and Radar Establishment, Malvern, U.K. Restricted document.

environment. The results summarised in Table 4 indicate that low emittance can be maintained only with clean surfaces since dust and water very quickly increase coating absorptance. Nevertheless, measurements have shown that an absorptance of at least 80% of the pre-soiled value can be regained if the coating is superficially cleaned.

Field trials should now be carried out to determine the effectiveness of these coatings for thermal countersurveillance.

distributions are shown in Fig. 7. As might have been anticipated from the known absorptance of soil [13], a heavy layer of dust when applied to the three samples studied resulted in very large emittances (typically ~ 0.87) and, where applicable, reflectance distributions characterised by a reduced specular component. However, "light" layers of dust also produced significant changes to sandblasted aluminium and IPB + Al flake emittance values. For example, $\alpha$ for sandblasted aluminium changed from 0.24 to 0.44. The results in Table 4 also show the expected increase in emittance when water [14] was smeared onto sandblasted aluminium.

## 4. DISCUSSION AND CONCLUSIONS

Low emittance coatings for countersurveillance in the 8-14 $\mu$m band can be produced from optical thin films, diamond-like carbon coatings or by using paint. A painted coating has the advantages of being simple to prepare and apply, relatively inexpensive and robust. The emittance from a selection of paints has been studied in this investigation and in some instances the values obtained compare very favourably with those of a diamond-like carbon coating [8] and a naval paint [16] already investigated for countersurveillance applications.

Low emittance paint coatings have been obtained by the addition of aluminium pigment to binders such as alkyd and an inorganic phosphate binder; 70 $\mu$m Al flake proved to be a more suitable pigment than either 12 $\mu$m Al flake or Al powder. The most encouraging results were obtained when 70 $\mu$m Al flake was incorporated into the inorganic phosphate binder, providing a coating which had both a low emittance (~ 0.20) at 10.6 $\mu$m and an acceptable diffuse reflectance distribution. The optical characteristics of these latter coatings depended on the brushing techniques employed during sample preparation, since the surface texture was found to influence the results.

Further work is needed to determine the optimum Al flake content that can be used with the inorganic phosphate binder. This will necessitate the inclusion of quality control procedures during paint manufacture and sample preparation to ensure reproducible results can be obtained for a given paint composition. Once this has been achieved however, varying the Al flake content should produce paints with differing but controlled values of emittance. Such coatings could be utilised to provide thermal camouflage of an object by using disruptive patterning to break up thermal signatures relative to those of the background. For example, the emittances obtained in this work from paint coatings based on an inorganic phosphate binder have ranged from 0.60 (IPB + Al powder) to ~0.20 (IPB + 70 $\mu$m Al flake). This approach to countersurveillance in the 8-14 $\mu$m band is desirable since a single-valued low emittance coating will not provide an effective thermal camouflage when an object is observed using modern thermal imaging equipment [15].

A major obstacle in utilising low emittance coatings for countersurveillance arises when the object is situated in a dusty or wet
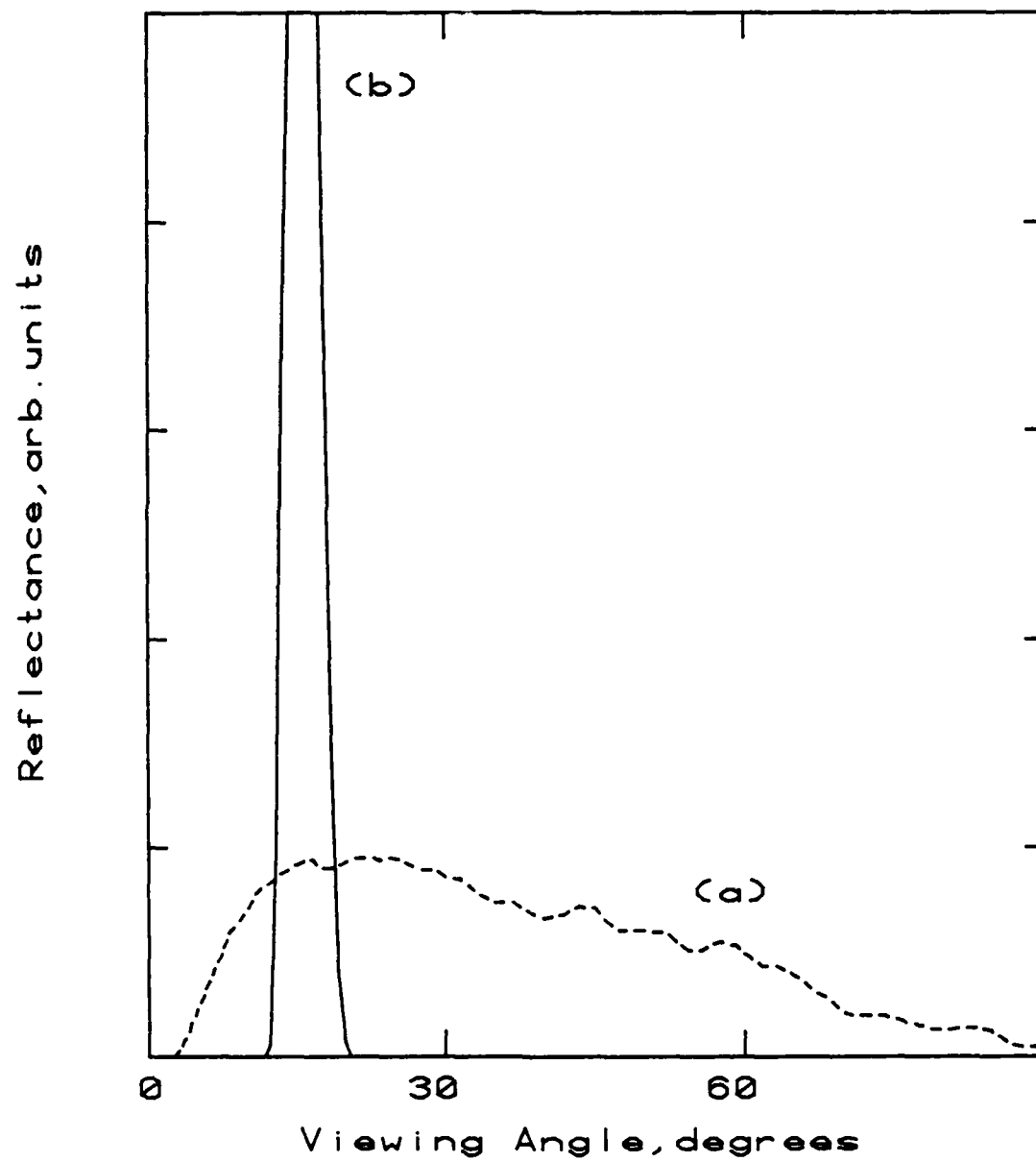
FIG. 3 - The reflectance distribution from; (a) sandblasted aluminium and (b) polished aluminium.
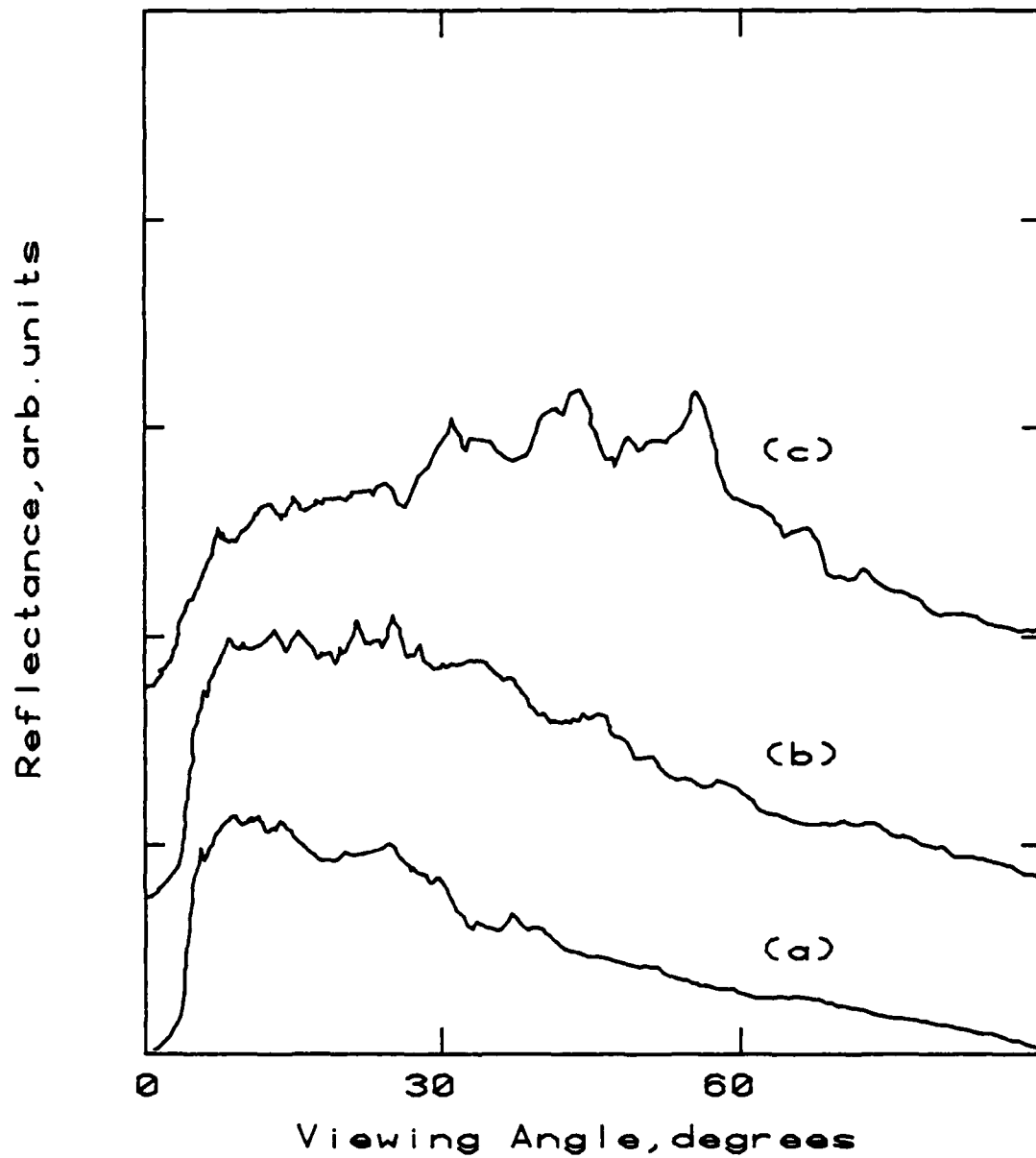
FIG. 4 - The reflectance distribution for sandblasted aluminium at various angles of incidence (a) $\theta = 5^0$, (b) $\theta = 10^0$ and (c) $\theta = 20^0$.
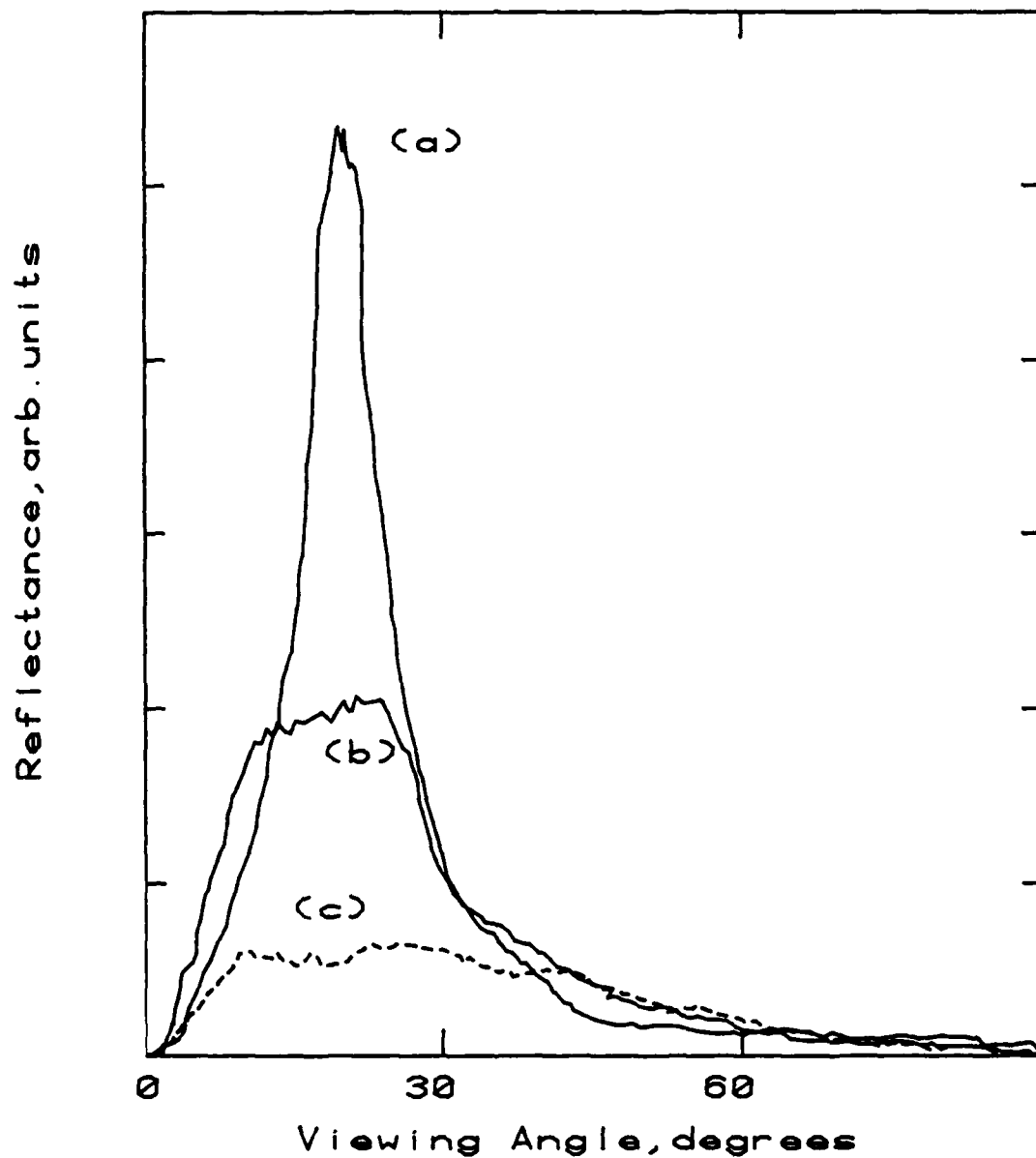
FIG. 5 — The reflectance distribution from alkyd pigmented with varying
concentrations of 70 μm Al flake. (a) 5% by wt., (b) 33% by wt.
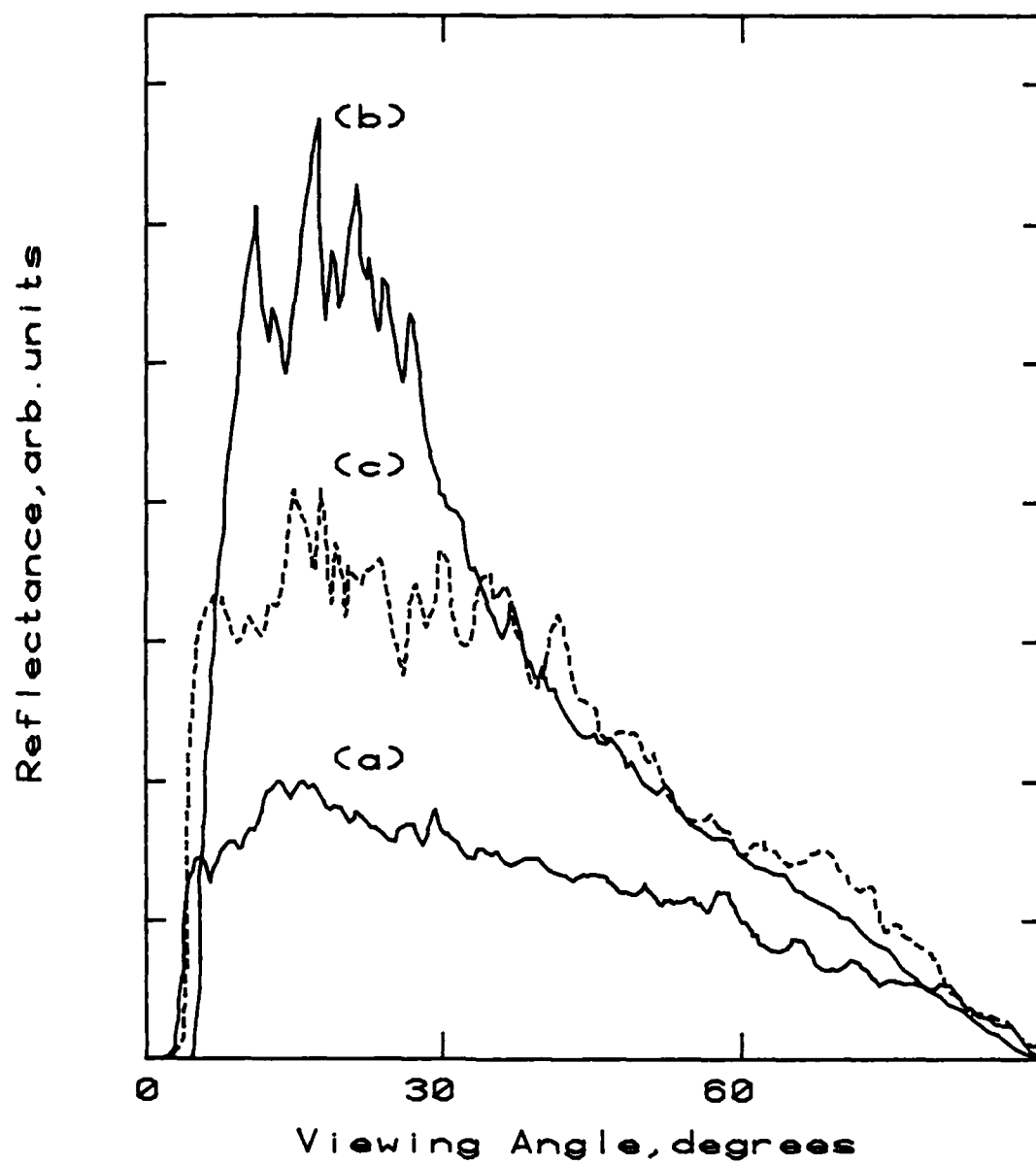Sandblasted aluminium is also included (c).

FIG. 6 - The reflectance distribution from; (a) Inorganic Phosphate + 40%
Al powder, (b) Inorganic phosphate + 70 μm Al flake and
(c) sandblasted aluminium.
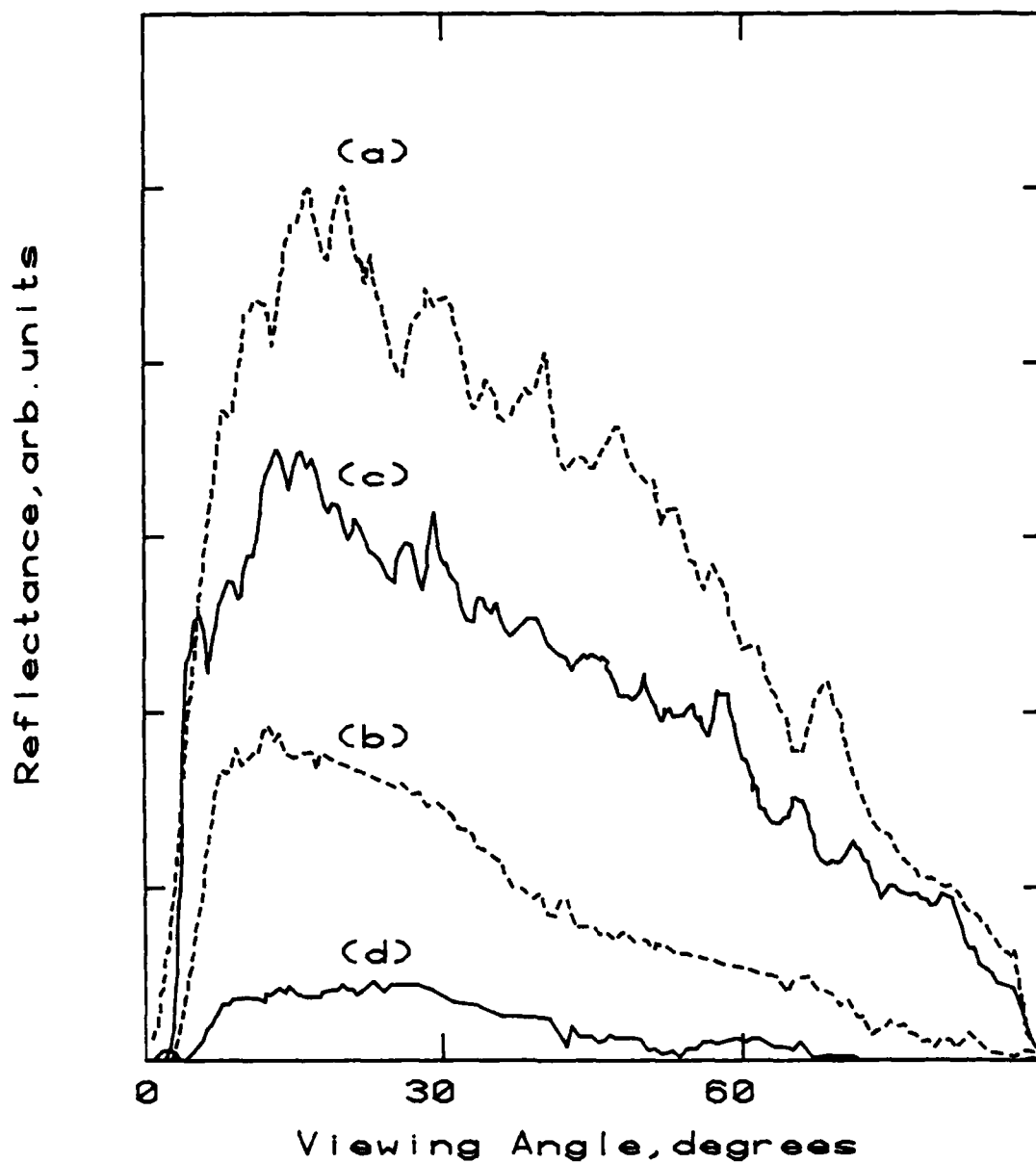
FIG. 7 - The effect of dust and water on the reflectance distribution from sandblasted aluminium and Inorganic Phosphate with 40% Al powder (IP40). (a) sandblasted aluminium, (b) sandblasted Al + dust, (c) Inorganic Phosphate with 40% Al powder (IP40), and (d) Inorganic Phosphate with 40% Al powder (IP40) + dust.

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